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INVESTIGATION OF HIGH POWER MHD GAS
LASERS

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General Electric Company

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This report presents the results obtained during the second half of the year 1974 in the study of MHD powered gas lasers. Key results of the work thus far are:

1. Changes to the shock tunnel and test facility include a modified cesium seed injection system, relocation of the secondary diaphragm, installation of a primary double diaphragm and a new CO₂ probe laser.
2. Gain measurements previously reported have been repeated, with substantial improvement in the signal attributable to the above changes.
3. Achievement of 19% enthalpy extraction in the MHD generator channel is an important step forward in generator performance.

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SEMI-ANNUAL REPORT

INVESTIGATION OF HIGH POWER MHD GAS LASERS

Contract No. N0014-73-C-0243

(1 Jan. '73 - 30 June '75)

Program Code: 3E20

Contract Value \$324,292

September 1974 to January 1975

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FOREWARD

The work discussed herein is being performed at the General Electric Company, Space Division, Space Sciences Laboratory, King of Prussia, Pennsylvania, under the auspices of the Office of Naval Research and the Defense Advanced Research Projects Agency. Mr. J. Satkowski of ONR and Mr. J. Meson of DARPA are the technical monitors.

The studies presented cover the period from September 1974 to January 1975 and represent an interim report of an ongoing project.

Dr. Bert Zauderer is the principal investigator. Mr. E. Tate is responsible for the operation and diagnostic evaluation of the facility. Messrs. W. Frey, F. McMenamin, and G. Fecik provide technical assistance in the operation of the facility. Mr. D. DeDominicis was responsible for the design of the new components for the facility. Dr. C. H. Marston contributes to the analyses and evaluation of the test results.

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I. KEY RESULTS OF THE PAST 6 MONTHS

1. An optical resonator and associated diagnostics and alignment hardware has been completed and installed on the shock-tube.
2. The shock-tube has been operated as a CO₂ gasdynamic laser to check and develop the resonator.
3. A CO₂ mixture with 1% xenon as a seed has been operated with lasing output in the presence of electric currents and a magnetic field. This was the primary task of the present contract - to get lasing from a magnetohydrodynamic plasma containing carbon dioxide.

II. PUBLICATIONS OF THE PAST 6 MONTHS

1. E. Tate, C. Marston, B. Zauderer, "Large Enthalpy Extraction Experiments in a Non-Equilibrium MHD Generator",
Applied Physics Letters, Vol. 25, No. 10, 15 November 1974.

III. CONTRACT EFFORT AND RESULTS

1. Introduction

The MHD laser concept combines the large power output capability of a fast flowing laser (gas-dynamic laser) and the efficiency of electrical pumping.

The MHD laser channel has a long (11"), narrow (0.125") throat through which the gas, brought to a suitable temperature and pressure by shock compression, flows into an expansion region where it is accelerated to a high velocity and the static gas temperature is lowered to $\approx 200^\circ\text{K}$ in the case of CO_2 . Addition of a small amount of easily ionizable species and the generation of electrical current by the MHD generator process (a voltage is generated by the conducting plasma flowing through a magnetic field) creates free electrons at a temperature well above the static gas temperature. These free electrons can pump a molecular species present in the gas to provide a population inversion.

The efficient creation of free electrons depends on the efficiency with which thermal power is converted to electrical power in the MHD generator process (enthalpy extraction). Within the past year an MHD generator channel (ST-40W) installed on the GE/ONR shock-tunnel facility has generated 1.82 megawatts of power at an efficiency of 19.3%. (Appendix B, Ref. 1)

Population inversion can be detected by a "gain" measurement in which a laser beam at the frequency of interest is passed through the plasma; if an inversion exists, the beam will be enhanced. Under the previous contract² gain exceeding 0.2% was achieved in the GE/ONR shock-tunnel employing CO_2 as the lasing species. During the present contract the gain measurements were considerably refined and were reported on in the last semi-annual report.¹ The measurement was developed to an accuracy of 1% (signal to noise ratio of one). The flow starting time was considerably reduced by relocating the secondary (reflecting) diaphragm from the front of the channel to the rear.

This also eliminated the passage of aluminum particles past the observation windows which also improved the signal.

The next experimental stage was to verify the gain measurements and fully prove the concept by actually getting laser operation. The accomplishment of this will be described in the next section.

2. Laser Experiments

a) Resonator

A description of the resonator has been given previously.²

The resonator has been completed and mounted around the shock-tube. One mirror was a spherical 99.5% reflector and the other a 98% reflecting Zn Se output coupler. The resonator configuration was not chosen to maximize power output but to (a) give as much stability as possible because of the vibrations present and (b) to ensure oscillation at small gains (i. e. to ensure that the gain/pass would exceed the window and mirror losses). The resonator is shown in Figure 1, 2, 3.

b) Gasdynamic Laser Experiments

Initial testing of the system was done using a "standard" gas-dynamic CO₂ laser mixture of 40 He/48 N₂/12 CO₂. An oscillogram of the lasing output is shown in Figure 4a with a gain measurement (Figure 4b) obtained under the same conditions for comparison. The lasing output has the same profile as the gain measurement but of course with no absorption spikes. The detector and circuitry for each measurement was the same; therefore, the less steady laser output is attributed to mirror and/or window vibration. Figure 5 shows the lasing output (a) and two experiments to eliminate the possibility of spurious infra-red radiation. In Figure 5b the 99.5% reflecting mirror was covered and the detector output was zero; in Figure 5c a chopper was located on the 99.5% mirror side of the resonator and it can be seen that the detector output returns to zero when the path is blocked.

c) Xenon Seeded Experiments with Applied Currents and Magnetic Field

Experiments with applied currents were done with 70 He/29 Ne/1Xe with the addition of various amounts of CO₂. Figure 6 shows the detector response for consecutive experiments in which the CO₂ concentration was increased from 2% to 5%. Oscillation starts at a CO₂ concentration of 4% and as it is estimated that the optical losses (including the 2% exiting the output coupler) are 3.2% then the path length of 27 cms. would indicate a gain/cm of .12% which is in agreement with gain measurements obtained under identical plasma conditions. This gas mixture does exhibit a freezing of the CO₂ vibrational levels and, therefore, will lase without the application of currents. Presently, the experimental effort is mostly directed at separation of this combined GDL and EDL lasing. The currents are applied by twelve isolated sources. The axial spacing from the window and the current density are the two main parameters being varied.

As the primary objective of this program is eventual generation of current (to provide pumping of an upper laser level) by the MHD generator effect, it is therefore essential to show that lasing can be maintained in the presence of a magnetic field. The present optical bench and associated quipment was designed primarily to be a stable base for the resonator and thus perform satisfactorily despite the mechanical vibrations present in shock-tube operation. Compromises in mechanical stability necessary for operation at large magnetic fields were not made. The magnetic field strength used was, therefore, kept below 0.8 Tesla and only the top half of the split solenoid was employed. Nevertheless, the field does move the bench enough during a run to cause misalignment. This is illustrated in Figure 7. The top oscillogram (a) is the magnetic field profile. Figure 7(b) shows normal GDL operation and 7(c) shows GDL operation with B field. Comparing 7(b) and 7(c) shows that the bench moves out of alignment

shortly after peak-field and moves back into alignment several milliseconds thereafter. When the bench moves back into alignment, the magnetic field is at about 80% of its peak value so the movement is mostly an eddy current effect which subsides after the magnet is crow-barred from a fairly fast (≈ 3.5 ms) sinusoidal rise to a slow exponential decay. A similar comparison for the xenon seeded mixture with applied currents is shown in 7(d) and 7(e). Figure 7e is of primary importance as it shows laser operation of a molecular species in the presence of electrical currents and a magnetic field. Modifications to the bench which will permit operation at larger magnetic fields are presently being made.

IV. REFERENCES

1. B. Zauderer, E. Tate, and C. H. Marston, "Investigation of High Power MHD Gas Lasers", General Electric Company, Contract No. N00014-73-C-0243, Semi-Annual Report, January 1974 to August 1974.
2. B. Zauderer, E. Tate, and C. H. Marston, "Investigation of High Power MHD Gas Lasers", General Electric Company, Contract No. N00014-73-C-0243, Annual Report, January 1973 to December 1973.

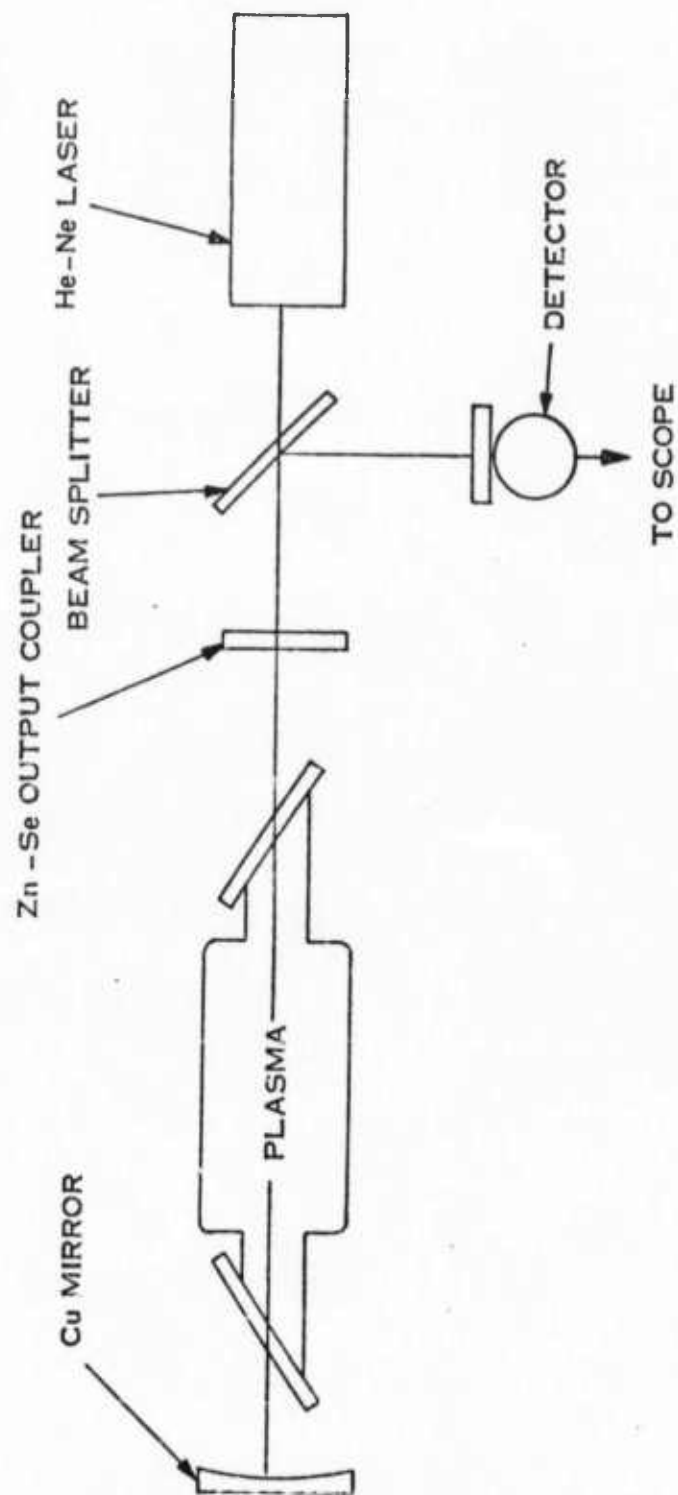


FIGURE 1 SIMPLIFIED SCHEMATIC OF MHD LASER CHANNEL OPTICS

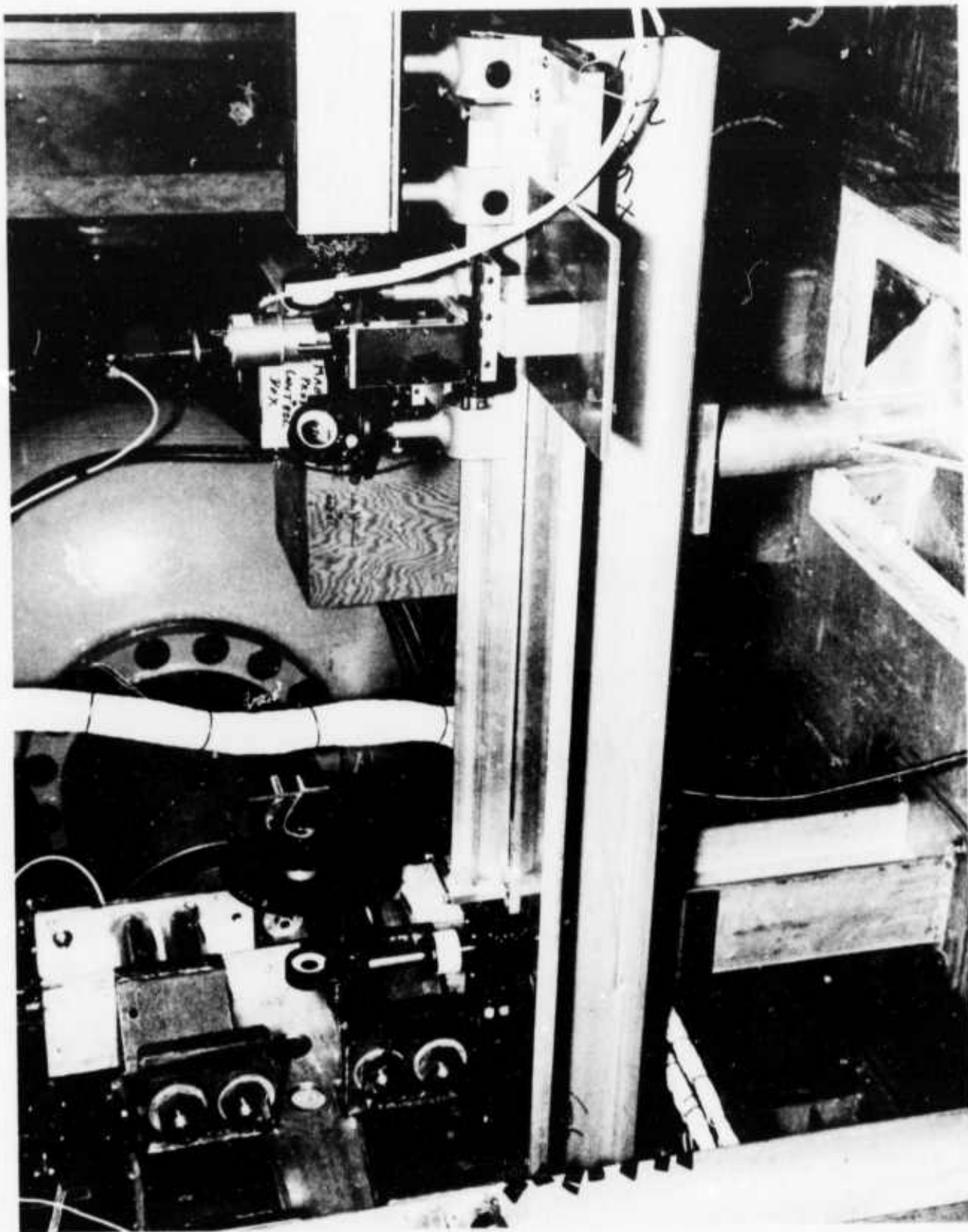


FIGURE 2 View of Output Coupler Side of Laser Resonator and Detectors

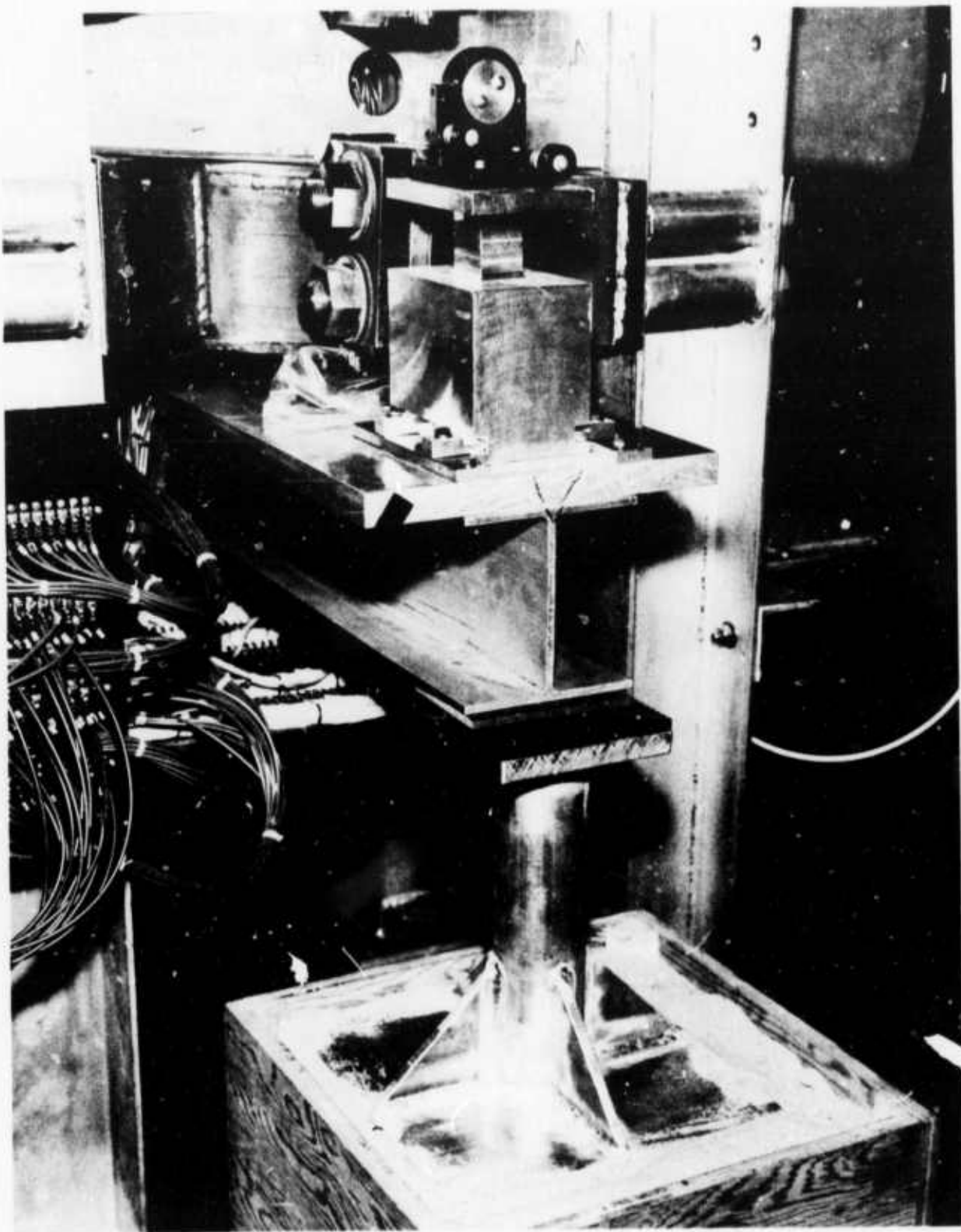
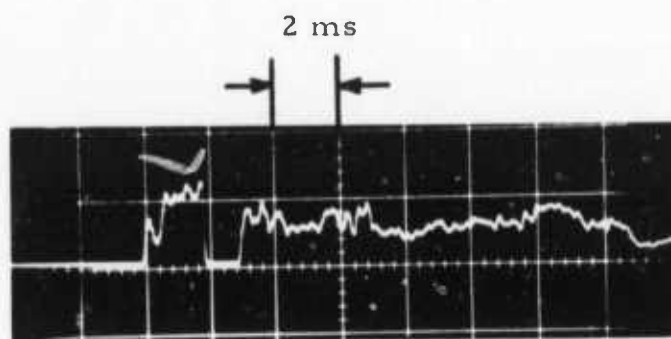
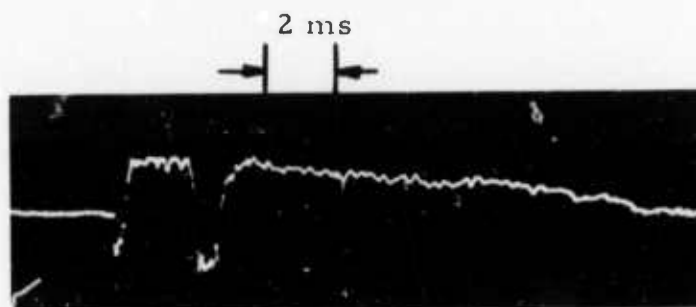


FIGURE 3

View of 99.5% Mirror Side of Laser Resonator

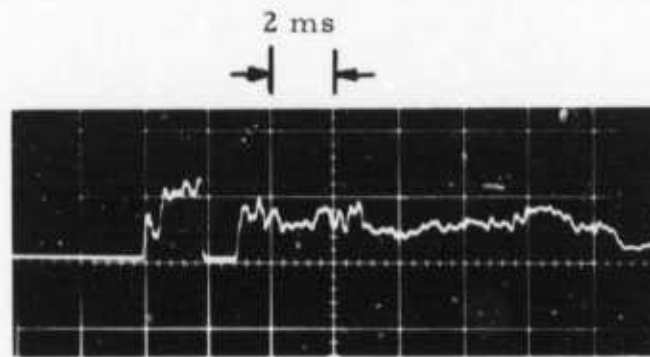


(a) GDL Lasing Output

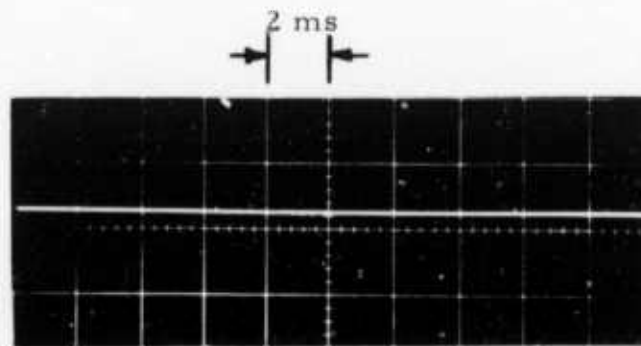


(b) GDL Gain Measurement

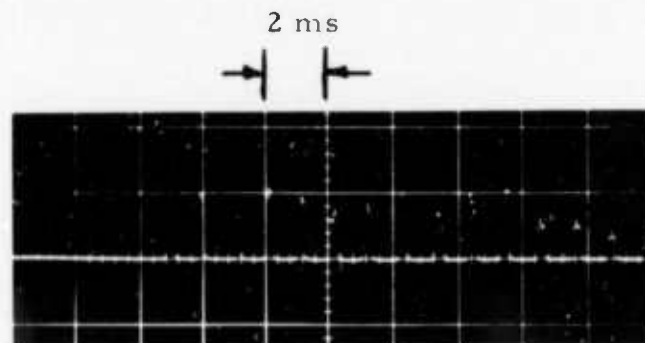
FIGURE 4 Comparison of GDL Lasing and GDL Gain



(a) UNCHOPPED SIGNAL



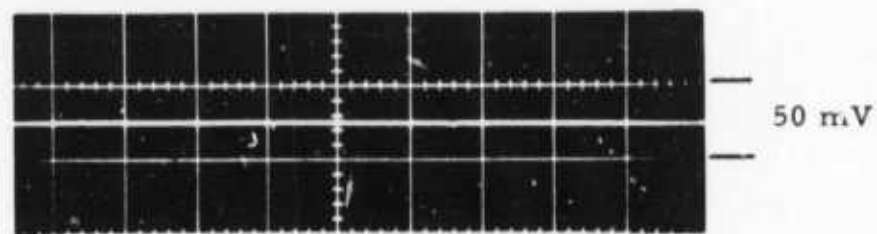
(b) SIGNAL WITH 99.9% MIRROR BLOCKED OFF



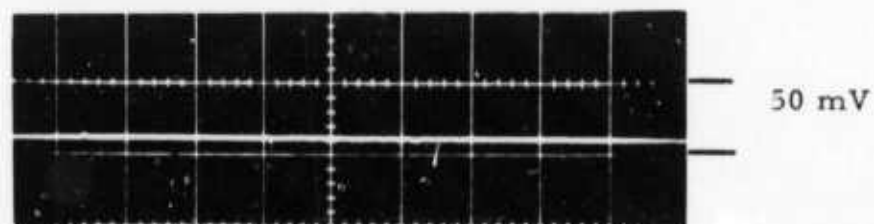
(c) CHOPPED SIGNAL

LASING OUTPUT SIGNAL OPERATING AS A GAS DYNAMIC LASER

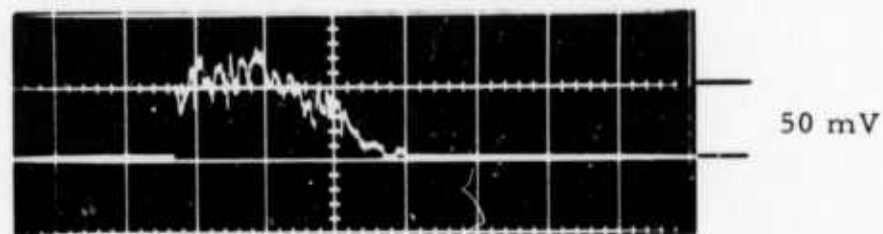
FIGURE 5



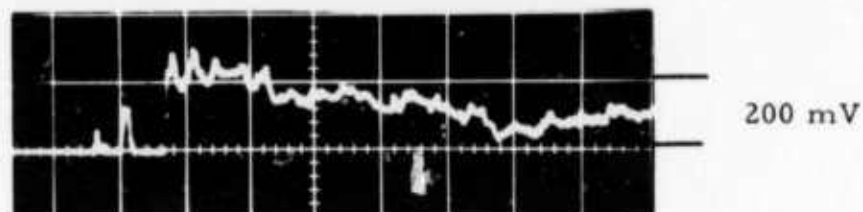
(a) CO_2 Concentration 2%



(b) CO_2 Concentration 3%



(c) CO_2 Concentration 4%

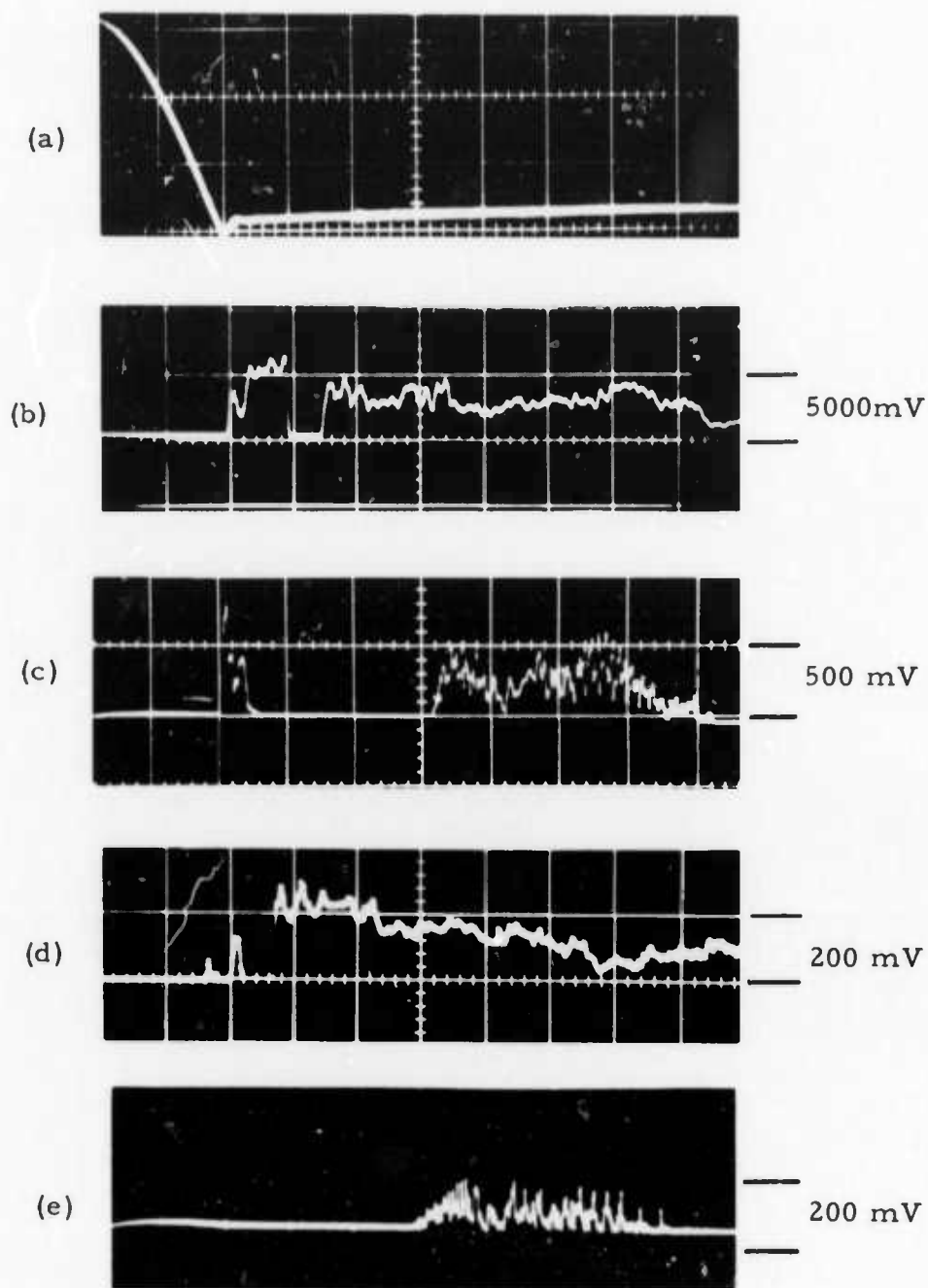


(d) CO_2 Concentration 5%

All Oscillogram at 2 ms/cm

FIGURE 6

Xenon Mixture Lasing Outputs with Applied Currents and Various Percentages of CO_2



- (a) Rate of change of magnetic field
- (b) GDL operation $B = 0$
- (c) GDL operation with $B = 0.8$ Tesla
- (d) Xenon seeded mixture with applied currents: $B = 0$
- (e) Xenon seeded mixture with applied currents: $B = 0.8$ Tesla

FIGURE 7 Lasing outputs with and without magnetic field